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Equation of the Underground Run-Off (Feeding) of Rivers in its

General Form

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EQUATION OF THE UNDERGROUND RUN-OFF (FEEDING)
OF RIVERS IN ITS GENERAL FORM

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Considering the hydrological and other methods for the computation of the volume of the underground run-off of rivers, we were convinced of their inadequacy^(1,2). The reason for the unsatisfactory results in the use of these methods is the tendency of the research workers to solve the problem of the underground run-off with relation to the entire river basin, without the preliminary studies of the conditions of underground feeding prevailing in its separate parts. Together with this, there is a tendency to exclude from the analysis the hydro-ecological conditions existing in the river basins, and to elude the start of the tedious study of the regularities of the water run-off from individual aquiferous strata as contributing to the general integration of what is known as the underground run-off of a river. By the very use of the graphic method for the solution of the problem by way of differentiation of the hydrograph, representing the general run-off of a river and constructed for a closing line of direction, the hydrologists have assumed average conditions for underground feeding of a river with relation to the entire basin. This assumption is wrong, if the variety of climatic, hydrologic, and hydro-geologic conditions existing in the river basin are taken into consideration. Such a general approach to the solution of the problem makes it impossible to investigate the real nature of the underground run-off of rivers, and to discover the basic regularities governing it. As a result of this, many very essential facets

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of the phenomenon, as, for instance, the run-off cycle from aquiferous strata, tied in hydraulically with the river (drained by the river bed), the distribution of the underground run-off in the annual cycle, etc., were not studied.

Bearing in mind the present achievements in hydrology and hydrogeology, such a diagrammatic solution of the problem is hardly adequate. Further progress in the study of the underground run-off of rivers is possible by the application of physical methods, which disclose the regular connection and relationship of phenomena. In other words, the time is here to undertake the determination of the underground run-off of rivers not by the differential analysis of the hydrograph representing the general run-off of a river, but rather by the incorporation of all observed phenomena into an integrated hydrograph of the underground run-off.

This can be accomplished by a detailed study of the run-off cycle of all categories of underground waters, which take part in the underground feeding of a river.

The regularity of the run-off from individual aquiferous layers, drained by the river bed, is determined by the conditions of stratification and feeding of the aquiferous layer, i.e., by its type (ground or artesian flow), and by the location of points of discharge (exits to the surface), with relation to the waterline at the river bank. Variations in the above conditions lead to variations in the distribution of the annual underground run-off from various aquiferous layers, i.e., to its phase displacement. Thus, the descending springs of ground feeding, opening above the river bank waterline, can be represented by a hydrograph, similar in form to the river run-

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off hydrograph. The difference is only in some phase displacement to the right along the time-axis (retardation), as compared to the hydrograph of the surface run-off. Investigations have shown that the run-off cycle from the aquiferous layers, hydraulically tied in with the river (with the free and pressure surfaces), has the line of direction of its run-off phases reversed, i.e., the homologue of the maximum surface run-off of waters of this category, and vice-versa. In their turn, the ascending springs feeding on the waters of the deeply embedded artesian aquiferous layers, and opening up above the river bank water level, do not develop fluctuations in the river flow, which are typical for the above described categories of underground run-off. It follows clearly from the above analysis that the correlations between the individual components of the underground feeding of a river are the factors upon which the hydrograph of the underground run-off of the river is predicated.

The phase displacement in the underground run-off, which is a result of various conditions of feeding and discharge of the individual aquiferous layers into the river drainage basin, becomes more complex by the asynchronous evolution of basic hydrological occurrences in the river basin. In the case of a river like the Volga, the spring maximum water level at its headwaters is registered 1 to 2 months earlier than at its lower course. The same time differential applies to the date of the stable summer water level, ice solidification, etc. For the aquiferous strata, the run-off cycle of which is tied in with the river cycle, the asynchronous development of hydrological processes is accompanied by an asynchronous development of the underground run-off, i.e., by its phase displacement in various parts of the basin. It is, therefore, necessary to study the

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underground run-off under homogeneous hydrological conditions, by breaking up the general river basin into smaller individual basins.

It follows from the above that the efforts directed toward the determination of a universal index, or coefficient, or criterion for the dynamics of the underground run-off, for an entire river basin of any significant size, or for rivers in general as it is being attempted by some hydro-geologists⁽³⁾, are bound to fail.

Based on the prior analysis and guided by the classification of the underground feeding of rivers⁽¹⁾, we write the equation of the underground feeding (run-off) of a river, in its general form, applicable to one of its sections (an individual basin):

$$W_y = W_r + W_a + (-W_o), \text{ or} \quad (1)$$

$$\int_{\Delta t} W_y = W_{rs} + W_{ro} + W_a + (-W_o), \quad (2)$$

where the following designations are accepted: W_y is the underground feeding (in its entirety) for the section of the river; W_a is the ground feeding; W_{ro} is the upper (seasonal) ground feeding; W_{rs} is the basic (or ground proper) feeding; W_o is artesian feeding; W_o is the negative underground feeding (the river feeds the aquiferous underground layers).

In their turn, the categories W_{ro} and W_a , by the characteristic of the hydraulic bond of the aquiferous layers with the river, which affects the dynamics of their run-off (the form of the hydrograph), are divided into hydraulically bonded (W_{ro}^{**} , W_a^{**}), hydraulically non-bonded (W_{ro}^{***} , W_a^{***}), and periodically bonded with the river (W_{ro}^{***} , W_a^{***}), i.e.:

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$$W_{ro} = W_{ro}^{*} + W_{ro}^{**} + W_{ro}^{***} \quad \text{and} \quad W_a = W_a^{*} + W_a^{**} + W_a^{***}$$

By substituting values into equation (2):

$$W = W_{rh} + W_{ro}^{*} + W_{ro}^{**} + W_{ro}^{***} + W_a^{*} + W_a^{**} + W_a^{***} + (-W_o) \quad (3)$$

The underground feeding (run-off) of the entire river (river basin) (4) equals:

$$W = W_{y,1} + W_{y,2} + W_{y,3} + \dots + W_{y,n} \quad (4)$$

where $W_{y,1}$; $W_{y,2}$; $W_{y,3}$... $W_{y,n}$ are values for the underground feeding (run-off) by individual sections of the river basin.

Equations (3) and (4) indicate that the determination of the volume of underground feeding for an entire river is a complex problem, which can only be solved by a sequence of series of operations, the order of which is controlled by the equations (3) and (4).

Thus, the hydrogeological computation of the volume of the underground run-off of a river may be accomplished not by way of differentiation of the hydrograph of the general river run-off, but rather by an integrated construction of the said hydrograph. This general hydrograph, representing the underground run-off of a river, may be constructed only after individual hydrographs, by individual river sections, were constructed, the latter, in turn, having been constructed from hydrographs, representing separate components of the underground run-off.

Such an approach to the solution of this problem is, in its

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underlying principle, different from the previous approach, and, undoubtedly, much more complex. However, regardless of its complexity, it is the only method, by which a correct and scientifically supported concept on the volume of underground waters finding their run-off through river systems, ~~can be arrived through river systems~~, can be arrived at. In the practical application of this method, the problem may be considerably simplified. For instance, the presence of all the components of the underground feeding of a river section, as per equation (3), is not mandatory. Individual components may be either absent, or be of such insignificant value in the general volume of the underground run-off, that they can be entirely overlooked, without affecting, to any significant degree, the ~~accuracy~~^{precision} of the computation. Specifically, such simplification, based on the knowledge of the hydro-geological conditions, must be effected in breaking up the river basin into individual sections.

The main difficulty in solving this problem, as presented in this thesis, lies in the thorough study of the cycle of, and the composition of the volume of the underground run-off from the aquiferous strata, which have a hydraulic bond with the river (being drained by the river bed). It is clear that this study cannot be based on direct measurements of the underground flow discharge, as is done when dealing with springs.

Some suggestions for the solution of this problem can be found in our previous ~~thesis~~^{article (2)}.

The study of river basins, based on the principles presented here, will make possible the zoning of rivers by types of underground feeding, each type to be represented by its hydrograph. Such zoning

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will, to a considerable degree, simplify subsequent research in the field of underground run-off of rivers, a phenomenon having ramifications far beyond the field of hydrogeology.

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